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IS THE PORTUGUESE BATTERY ELECTRIC VEHICLES SUBSIDY PROGRAM ENCOURAGING THE "RIGHT" CONSUMERS?

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Abstratct:

To achieve carbon neutrality, the Portuguese government put in place a battery electric vehicle (BEV) subsidization program. By focusing on the non-additionality concept, we show that the percentage of BEVs buyers who would have bought them without the subsidy is smaller for low income households (more price sensitive) than for other households and corporations (27,43% vs 29,99%). Moreover, the welfare positive consequences for consumers are greater when targeting low income households, given that there are more marginal consumers who will be able to purchase a BEV. This results in lower CO2 emissions and increasing positive externalities. In summary, discriminating across different consumers is required for cost-effectiveness.

Keywords: Battery Electric Vehicles, Subsidies, Additionality, Own-Price Elasticity of Demand, Willingness to Pay

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Climate change fight is way far from being over and as Winston Churchill said in times of War: “Now this is not the end. It is not even the beginning of the end. But it is perhaps, the end of the beginning.”.

1. Introduction

In the last decades the world has been witnessing the effects of mankind’s technological evolution, followed by massive production and consumption. This progress enhanced countries to achieve fast economic growth, as major examples China and India, with relevant improvement of economic standards. The population has grown exponentially, from 2.6 billion in 1950 to current 7.8 billion, while the expectations are that by 2100, the number will reach the 11 billion mark (United Nations, 2020).

Hand in hand with such societal transformation there are the hazardous consequences to the environment and to the survival of the planet. According to the PBL Netherlands Environmental Assessment Agency 2019 Report, in 2018 the global greenhouse gas (GHG) emissions were 57% higher than in 1990. This massive increase, with considerable annual growth rates, contributed to the rise of global temperatures, and 9 out of the top 10 warmest years occurred since 2005 (records started in 1880).

The abovementioned negative environmental impacts have placed climate change and sustainable development in the core of the international political agenda. The increasing awareness that the measures implemented so far were not strong enough, have encouraged the 197 Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to adopt the Paris Agreement. The treaty establishes that global temperatures rise should be kept well below 2 degrees Celsius when compared to pre-industrial levels and provides the framework to guide nations in their paths to achieve the goal to carbon neutrality by 2050. Even though the United States of America, under Trump’s administration, decided to withdraw the agreement, it was broadly accepted by the 197 nations. However, the doubts concerning the effectiveness of the signatures rose rapidly. With Greta Thunberg in the lead and with the motto that there is no planet B, younger generations demand effective and timely actions from politicians and corporations.

With the aim of complying, not only with the Paris Agreement, but also with citizens' requests, the European Union is the frontline of that battle, having approved the European Green Deal in the end of 2019. One of the focus of this European Agreement is on transportation (Communication European Commission 2019). It represented 28% of the total EU's carbon emissions in 2018, with cars as the mean of transportation which contributed the most, representing 43% of the total (Transport & Environment, 2020). In this context, electrification of the economies, in general, and of transportation, in particular, plays an important role, taking advantage of the significant increase in the production of electricity from renewable energy sources. Hence, several European countries have created incentives to decarbonize their citizens' fleet, promoting electric vehicles. So, the aim of this project is to contribute to the discussion about the Portuguese electric vehicle incentive's program, so that the goal of carbon neutrality can be achieved in the most cost-effective way.

The effect in sales may be somehow correlated with these incentives, with a promising 7.8% share of electric vehicles in the EU 27 countries for the first half of 2020 (Transport & Environment, 2020). Their consequences to the Portuguese electric vehicles sales were the base ground to develop this work project.

The main results, both analytical and graphical, are supported by simulations which based on a constant price elasticity demand function and a linear supply function. Battery electric vehicles' buyers were divided in two groups: low income households and high-income households plus corporations. An own-price elasticity of demand was attributed to each group and by equating the two functions a market equilibrium was obtained. In a second step, it was defined a 3-unit subsidy amount that was incorporated in the demand function by substituting the demanded price (P_b) by the seller price (P_s) minus 3. After equating this new demand with the supply function, we reached the equilibrium prices and quantities with the subsidy. From these values it was possible to calculate non-additionality percentages, which represent the portion of buyers who would have acquired a 100% electric vehicle regardless of the existence of the subsidy. Low income households, with a more elastic demand, presented the lowest percentage, 27,43%, compared to the 29,99% obtained by the high-income households and corporations. Although, this difference is almost insignificant, it supports the message that it is more cost-effective to subsidize more price sensitive buyers, given that there will be more marginal consumers who will be able to buy a battery electric vehicle.

Moreover, using a graphical analysis with the above mentioned price and quantity's values, with and without the subsidy, it is assessed that by subsidizing more inelastic consumers, the government is reducing the equilibrium price for buyers whose willingness to pay (WTP) is larger than the initial market price and so would not need the grant to buy these vehicles. On top of this the decrease in equilibrium prices with the subsidies is larger for this group when compared with low income households. Due to this, the positive externalities, which arise from additional battery electric vehicles purchases, will be reduced when targeting less price sensitive demands and will not compensate as much as expected the deadweight loss created by the subsidy.

The above findings translate that without any further requirements, the current Portuguese subsidy scheme is not cost-effective.

The remainder of the paper is organized as follows. In section 2 a literature review is undertaken, focusing on the electric vehicles market, public policy incentives and their cost effectiveness. The Portuguese Electric Vehicles Incentives will be detail, followed by interesting results from a survey exclusively created for this final thesis. Then, a theoretical framework with the most important concepts will be presented, complemented by different, previously mentioned, simulations to evaluate possible answers to the research question. Finally, there will be time to acknowledge important conclusions from the results obtained and to provide some policy recommendations.

2. Literature Review

Electric vehicles (EVs) can be divided in 5 different categories: Battery Electric Vehicles **(BEVs)**, Plug-In Hybrid Electric Vehicles **(PHEVs)**, Hybrid Electric Vehicles **(HEVs)**, Extended Range Electric Vehicles **(EREVs)**, and Fuel Cell Electric Vehicle **(FCEVs)**. For the purpose of this work project and literature analysis only the first three are relevant. The **BEVs** are 100% electric vehicles, with electric motors and batteries recharged in any electric power source. These are the focus of the most recent Portuguese incentive program. The **PHEVs** use both an electric motor (supported by rechargeable batteries) and a gas engine in its driving. These two categories are usually grouped into one single definition: Plug-In Electric Vehicles **(PEV)**. Finally, the **HEV** are models similar to **PHEV**, however, do not have the possibility of recharging their electric batteries. In this case, the electric motor complements an internal combustion engine for fuel efficiency purposes (Current EV, 2019).

As stated before in the introductory section, the market and the sales for PEVs is growing at a promising rate and China is one of the biggest contributors. Wang et al. (2017) provide a broad picture of the Chinese market, explaining how the country was able, not only to surpass the US sales, but also to make them grow 343% from 2014 to 2015. The authors present the numbers for the massive monetary incentives granted. However, they report that the introduction of the free licence plate scheme (non-monetary incentive that enhance car ownership) was the most relevant incentive for consumers to purchase a PEV. Finally, the authors mention that there is unsustainability related to these incentives and that more cost-effective policies must be introduced.

Chandra et al. (2010) evaluate the hypothesis whether the tax rebates, provided to HEV new purchases, were cost effective in environmental terms. The data corresponded to all the Canadian provinces between 1986 and 2006 and the first major conclusion was that a $1000 tax rebate incentive would increase, on average, the share of HEV sold by about 34%. Although this result could be considered to be positive, the authors show, through a counterfactual analysis, that the incentives were encouraging not only consumers that would buy HEV regardless of the existence of the tax rebate, but also consumers that are more prone to drive more fuel efficient cars (known as non-additionality). All together $195 was the cost per tonne of carbon saved, way above the price of carbon in the market. Similar results were presented by Azarafshar et al. (2020) for the period 2012 to 2016, and for PEV, instead of HEV.

Sheldon et al. (2019) go one step further and instead of only evaluating the cost effectiveness of PEV subsidies they analyse which subgroup of consumers should be targeted. Their results demonstrate that when focusing on consumer heterogeneity, 85 to 95% of the subsidy budget is directed to people who would not purchase a PEV without this support. Moreover, the share of total sales attributed to the subsidy would rise from 17 to 30%. Their recommendation is that a policy with the aim of increasing the share of PEV sold should target low income consumers. Davis (2018) also points out that the incentive policies should encourage the best fitted groups, so that not only the share of PEV increases but the environmental benefits are greater. Since a subsidy or a tax credit do not take into account whether EV consumers drive more or less miles, a carbon tax would be a better solution to achieve the previously mentioned goal.

Alongside with the idea of evaluating subsidies' cost effectiveness, Xing et al. (2019) link every EV model to a proper substitute counterpart (consumer second choice). The authors contributed with valuable insights regarding the connection between price elasticities of demand and their impact in the share of consumers that would have bought EVs regardless the availability of the subsidy (non-additionality). Their paper and theoretical concepts were the major contribution to the development of this work project and in a later section will be detailed and properly defined.

Moving to the European market, Yan (2018) considers an internal combustion engine (ICE) model as a substitute to different BEV models, and evaluates whether there are positive savings in switching from the former to the latter in 28 European countries. Taking the example of Portugal, the author concludes that in 2014 BEVs were 4434€ more expensive than an ICE model. Moreover, the author also estimates an increase of 3% on average in the market share of BEV sales with a 10% increase in tax incentives. One significant contribution for a broad and detailed European analysis of the effect of different incentives, both monetary and non-monetary in the market share of PEV, was performed by Munzel et al. (2019). Based on a panel data for the 32 larger countries, the authors find a 5,4% average increase in PEVs' sales share for a 1000€ increase in financial incentives.

2.1 Consumer behaviour and willingness to pay

Focusing on consumer targeting, Yang et al. (2019) complement the literature by analysing which specific groups are more prompt to be encouraged by the incentives. After conducting a survey on incentive adoption intention and regressing the data obtained, the authors concluded again that "lower income exhibit higher acceptance and interest in the policies". A similar approach was conducted by Lin et al. (2018) with the relevant result that for the Chinese consumers surveyed, one of the most influential factors to buy an EV is the noticeable pollution in the biggest cities (smog). They also end up obtaining similar conclusions related to heterogeneous consumers' characteristics, such as gender. In both studies females are more willing to purchase an EV.

When exploring the EVs' market is important to keep in mind that the price premium for such models (monetary difference for a non EV counterpart) is usually high, even when including all the possible savings (Yan (2018). Hence, different authors have developed econometric models to estimate the willingness to pay for EVs' consumers. Liu (2014) focuses only on HEVs data sales for the US in 2009 and acknowledges a considerable negative difference between the WTP (between $963 and $1718) to the price premium at the time (around $5000). For the author, it is clear that the amount of the subsidies granted should take into account this discrepancy. A similar conclusion was reached by Discroll et al. (2013) according to which only a non-realistic $50 000 grant would be enough to meet the 10% HEV market share. Concerning the BEVs' case specifically, Breetz et al. (2018) claim that it may not be reasonable to continue to subsidize them due to their high purchasing price and lack of competitiveness (Nissan Leaf model would require more than $10 000 in incentives to become competitive). Moreover, in Ayetor (2020), about Ghana's government incentive proposal of exempting the payment of import levy, only second handed electric vehicles, with at least 3 years of usage, could become competitive with non-EVs models.

Noel et al. (2019) brought this willingness to pay question into the European context, more specifically to the 5 Nordic countries. However, the research was not only focused on the car itself, but also on consumers WTP for each characteristic (for example acceleration and driving range). As one would predict recharging time and driving range are, among all the other characteristics evaluated, the ones that are statistically significant in all countries with an average of 5600€ for each hour reduced in recharging time and 150 € on average per additional kilometre considering driving range. Again, these results cannot be ignored when designing a cost-effective subsidy policy.

2.2 Broader policy recommendations and review conclusion

Matthews et al. (2017) provide an interesting approach to increase EVs' adoption. While focusing on dealerships in Ontario, Canada, their survey findings suggest that once a salesperson is well trained to demonstrate a positive attitude towards EVs, and if these models are frequently available on site, the chances of consumers deciding to buy them increase.

As a final note in this literature review, it is relevant to state that questions are raised about the environmental benefits of PHEVs and whether they should be supported by state incentives. The European Federation for Transport and Environment 2020 study "A new Dieselgate in the making", reflects this position, namely that PHEVs models are not as environmentally friendly as they are announced to be by their brands' test results. In a 100 kms journey for example, driving one of the considered models could result in around twice the amount of CO_2 emissions when compared with brands' official results.

In contrast, Constestabile (2017) argues that the policy schemes should target small range BEVs and long-range PHEVs. By analysing more in detail the UK and California markets, in a long-term perspective, long range BEVs were far from being competitive and would only create a growing instability on the incentive's sustainability. For the author the continuous development and reinforcement of long-range PHEVs would open doors for the technological progress in batteries, so that long-range BEVs would turn out to be a viable option. In summary, this review highlights that only properly designed policies, focused on buyers' heterogenous characteristics and WTP will make possible for countries to increase their share of EVs in a cost-effective way.

2.3 EVs' incentives in Portugal

In this section, the different incentives in place in Portugal for 2020 are presented, dividing into incentives targeting households and companies. However, first, tax benefits that are common to both groups are detailed, and then an overview on the subsidization program general rules is presented.

In Portugal cars are subject to different taxes. Two of them are the Imposto sobre Veículos (ISV) and Imposto Único de Circulação (IUC). The former is a one-time tax paid upon purchase and the latter is paid once a year. Both taxes calculations are related to CO_2 emissions and engine cylinder capacity.

Concerning IUC, only the BEVs are exempt given its 100% electric feature. Regarding ISV, BEVs are again fully exempt. PHEVs and HEVs have a 75% and 40% exemption rate respectively.

Additionally, the VAT from electricity expenses related to battery charging can also be deductible, but only when the vehicles are charged in public chargers or the owners have an electricity meter exclusive to their charger, so that it can be discriminated in the electricity bill.

Regarding the subsidies it is important to underline that, within EVs categories, they are only available to BEVs, up to a maximum purchase price of 62 500€ (including VAT). The vehicles' categories subject to the program are divided in 4 groups: Light Passenger Vehicles; Light Commercial Vehicles; Electric Bicycles, Motorcycles and mopeds, Load Bicycles; and finally, Traditional Bicycles. The candidate is able to ask for more than one incentive, so one can receive a subsidy for a light passenger vehicle and for a motorcycle. This incentive scheme will be the main focus of my analysis in this work project.

2.3.1 Households

In Table 1, the subsidies' granted by the Portuguese government to support households' purchases are presented.

Table 1: Government subsidies to households by vehicle category

	Households	Maximum # of grants
Light Passenger Vehicles	3.000€ Limited to 1 incentive per candidate	700
Light Commercial Vehicles	3.000€ Limited to 1 incentive per candidate	300*
Electric Bicycles, Motorcycles and mopeds, Load Bicycles	50%, up to a maximum of 350€ Limited to 1 incentive per candidate	1000*
Traditional Bicycles	10%, up to a maximum of 100€ Limited to 1 incentive per candidate	500*

Source: Fundo Ambiental 2020

* corresponds to common grants, both to households and corporations

2.3.2 Corporations

In 2020, companies also benefited from the subsidization program. In Table 2 all the values for the different vehicle category are detailed. It is relevant to point out that for light passenger vehicles, in comparison to households, not only the subsidy decreases to 2000€, but also the maximum number of grants also falls, from 700 to 300. Moreover, corporations are able to apply to 4 incentives per candidate instead of the previous limit of 1 (excluding traditional bicycles).

Table 2: Government subsidies to corporations by vehicle category

	Corporations	Maximum # of grants
Light Passenger Vehicles	2.000€ Limited to 4 incentive per candidate	300
Light Commercial Vehicles	3.000€ Limited to 4 incentive per candidate	300*
Electric Bicycles, Motorcycles and mopeds, Load Bicycles	50%, up to a maximum of 350€ Limited to 4 incentive per candidate	1000*
Traditional Bicycles	10%, up to a maximum of 100€ Limited to 1 incentive per candidate	500*

Source: Fundo Ambiental 2020.

* corresponds to common grants, both to households and corporations

In addition to the abovementioned subsidies, corporations can also take advantage of different fiscal incentives.

VAT

The VAT amount, 23% of the purchasing price, of PEVs can be fully deducted. For BEVs the limit price considered is 62 500€ and for PHEVs 50 000€ (both without VAT). As an example, a car that costs 40 000€ (including VAT) will end up costing 32 520€, almost 8 000€ in savings for the company.

Depreciation and amortization concerns

A vehicle owned by a firm can be depreciated at a maximum yearly rate of 25%. In accounting terms that amount is considered an expense and will then decrease previous fiscal year’s total profit subject to income tax. However, and like in the VAT case, there is a limit purchasing price that can be considered for depreciation and amortization purposes. In diesel/gasoline cars this amount is 27 500€ but for BEVs and PHEVs it increases to 62 500€ and 50 000€ respectively.

Autonomous taxation (i.e "Tributação autónoma de veículos para empresas")

Depreciation and expenses related to vehicles' usage are subject to an autonomous tax, on top of income tax. The rates differ depending on the purchasing price (VAT included) and whether the company presented profits or losses (in case of losses the tax rate increases 10 p.p). In summary, BEVs are exempt from paying this tax (either in profits or losses) and PHEVs pay around half of the tax applied to diesel/gasoline cars. Natural gas vehicles (NGV) also benefit for a reduction in this tax. In Table 3 the rates from this autonomous tax are detailed for the different vehicles categories.

Table 3: Autonomous taxation rates

Vehicle Price	Gasoline/Diesel	PHEVs	BEVs	NGL
Below 27 500€	10%	5%	0%	7,5%
Between 27 500€ and 35 000€	27,5%	10%	0%	15%
Above 35 000€	35%	17,5%	0%	27,5%

Source: Autoridade Tributária e Aduaneira, 2020

3. Battery Electric Vehicles' Survey

A 9-question survey was created as a complement to the development of this thesis. Portuguese was the language used, so that it could reach, in an easier way, a larger audience. In Table 4 from Appendix A all the details concerning the survey questions and respective options are presented.

3.1 Survey Data and Findings

The survey was shared for about 3 weeks, ending up with 366 people responding to the 9 questions. On the one hand, in the figures 1 to 9 of Appendix B, we can see a percentage distribution for the option chosen in each question by the respondents. On the other hand, the same information, but in absolute values, is presented in tables 5 to 13 of Appendix C.

The sample is somehow heterogeneous gender wise with 58% females and 42% males (Figure 1). From question 2, it is relevant to notice that young adults, below 35, represent 46% of the sample which may have a positive impact regarding environmental concerns (Figure 2). Focusing in monthly net income, the sample is characterized as a medium-low class sample with around 50% of the people earning less than 1500€ per month in net terms (Figure 3). Only 1% (4 people) owe a BEV and the thoughts about considering buying one were split homogenously, with 55% answering "Yes" and 44% "No" (Figure 4). The sustainability and environmentally friendly aspect of a BEV is a valuable reason to 80% of the sample, while 45% and 59% are interested in the existence of subsidies and long-run savings respectively (Figure 5). Regarding kms driven per day, only a residual 7 % of the sample drive on average more than 100 kms, which means that the majority would accommodate easily to the BEVs' battery autonomy (Figure 6). Question 7's answers send the message that the purchase price of a 100% electric vehicle might still be a considerable barrier to the survey participants. 51% of the respondents were only willing to pay up to 20 000€ (Figure 7). Considering that the cheapest and still less attractive models cost around 25 000€ (Guia do Automóvel, 2020), this valuation is far from desirable amounts. However, there are positive signs related to what these buyers are willing to pay more for a BEV when comparing it to a similar ICE (in terms of the general characteristics). 52% would be willing to pay more than 1000€ (Figure 8). This might be grounded in one or more of the reasons to buy a BEV presented previously, such as long-term savings or environmental concerns. Finally, and probably surprisingly, only 28% of the 366 people (Figure 9) were aware of the existence of a 3000€ subsidy to acquire a BEV (if the buyer is a households).

Through a Pivot Table Analysis of the data on can complement the above general presentation with a specific characterization of different income groups concerning willingness to pay.

In Table 14 below it is represented the number of people in each income group (excluding students and people who preferred not to say) that are willing to pay below 25 000€. Given their WTP, these potential buyers would for sure not buy a BEV without any subsidy, given the high purchasing price nowadays. In opposition, people above the 25 000€ WTP would be potential candidates to acquire a BEV regardless of the incentives, making the 3 000€ households' subsidy less relevant. As seen in the table, we conclude that the majority of these individuals are in the lower income ranges.

Table 14: Number of people with WTP below 25 000 in each income group

Income Group	Column A 15 000 - 20 000	Column B 20 000 - 25 000	Sum of Column A and B
0 - 500	5	3	8
500 - 1000	71	21	92
1000 - 1500	43	22	65
1500 - 2000	21	14	35
2000 - 2500	4	6	10
+ 2500	2	3	5
	146	69	215

Source: Survey Data

As a final remark of this survey analysis, it is important to state that all the results were based on a sample which is not representative of the Portuguese consumers, given the number of valid answers (366). This means that the information gathered is biased and is only relevant as a starting point for a reliable and well-founded conclusion later.

4. Theoretical Background

In this section we introduce the methodology that allows us to answer the research question of this work project, namely, if when purchasing electric vehicles the state subsidies are granted to the "right" consumers, that is, to those that would not buy them otherwise (Literature Review, section 2.1). In other words, we are concerned about additionality. If the resources are granted to those that would buy those cars anyway, then resources are being misallocated with negative impact on welfare. Since resources are scarce, the opportunity cost of misallocating them is very high. Moreover, from the public policy perspective that aims to increase the adoption of electric vehicles by incentivizing those that would not buy them otherwise, the government is reducing the impact of the policy and transferring resources to those that would not need them. So, the policy is not cost-effective, and the overall impact of positive externalities is reduced. Having this in mind, and from a theoretical perspective, we consider first the consequences of implementing subsidies, and then, following Xing et al. (2019), we show how additionality can be tracked.

The figure below illustrates demand and supply curves when the subsidization program is put in place. As it is well-known, a *specific subsidy* on the demand side shifts the demand curve upwards by exactly the same amount of the subsidy.[1] This occurs, given that for the same quantity sold, the willingness to pay of BEVs' buyers increases by 3 000€ and 2 000€, for households and corporations, respectively. With this shift in the demand curve the new equilibrium price (P_s) will be higher than the previous (P_1). However, the final price to buyers

[1] In addition to *specific subsidies* there can be *ad valorem subsidies* which are conceived as a percentage and not as a set amount. Given the Portuguese incentive scheme, which grants specific euro amounts to each buyer, it is only relevant to analyse the impacts of a *specific subsidy*.

(P_b) will correspond to the selling price (P_s) minus the subsidy granted by the government. Therefore, the quantities sold with P_s are larger than with P_1. In the end, there is a win-win situation for both consumers and producers, as both consumer and producer surplus increase after the subsidy.[2]

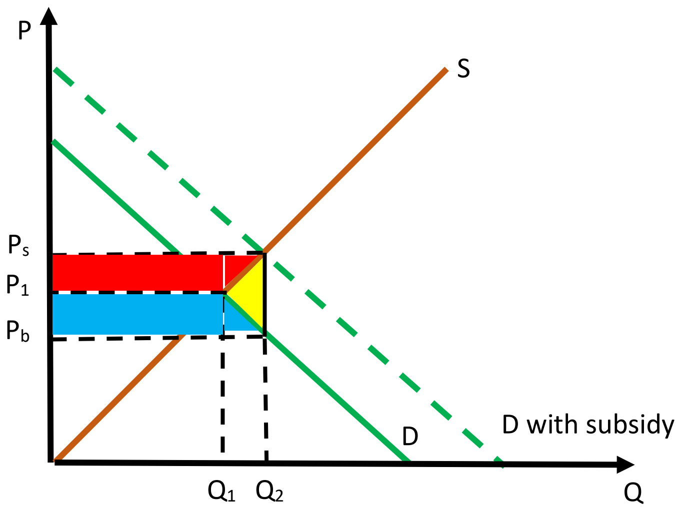

Figure 10: Subsidy impact in the market equilibrium

Source: Own Source

Concerning the welfare impacts, the subsidy increases Consumer Surplus by the light blue area and Producer Surplus by the red area, corresponding to the government transfers do consumers and producers, respectively. The total subsidy cost that is supported by the government is the area given by ($P_s – P_b$) x Q_2, that is, areas blue, red and yellow all together. Due to the subsidy, there is a Deadweight Loss for society given by yellow area, being one of the caveats of subsidies. However, in order to derive the total cost for society resulting from BEVs' adoption the social benefits due to emissions reduction have to be accounted for. By subsidizing only electric vehicles' buyers who otherwise would have bought a carbon emitting vehicle, preventing non-additionality, governments are contributing to decrease CO_2 emissions.

[2] The result would be the same if producers receive the subsidy instead.

This spill-over positive effect from subsidization programs also contributes to bring the market equilibrium closer to the social optimal.

Additionality of a BEV subsidy

Recall that non-additionality corresponds to the percentage of BEVs (in the specific case of this work project) that "would have been bought without the subsidy". If the value is close to 100%, it means that the subsidy is not an effective policy and it is not encouraging **additional BEV sales**. Based on Xing et al. (2019), and using the same notation as in Fig. 1, we may write

$$N_A(\%) = \frac{Q(P_1)}{Q(P_b)} * 100 \; (=) \; N_A(\%) = \frac{Q_1}{Q_2} * 100 \tag{1}$$

where N_A (%) represents the share of BEVs that would not have been bought without the subsidy, that is, "non-additionality".

By differentiating (1) with respect to the subsidy, we obtain that the share of BEVs bought without the subsidy depends solely on their own-price elasticity of demand, as follows:

$$\frac{dN_A}{ds} = \frac{Q(P_1)}{Q(P_b)} * e_D \tag{2}$$

where

$$e_D = \frac{\Delta Q / Q}{\Delta P / P} = \frac{\%\Delta Q}{\%\Delta P} \tag{3}$$

represents the own-price elasticity of demand[3].

[3] A value between 0 and -1 refers to an inelastic demand, where consumers are not that sensitive to price changes (examples of necessity goods like bread and water). If is it is below -1 (from -1 to - ∞) one is facing an elastic demand (goods like cars and soft drinks). There can be also extreme cases: perfectly elastic (- ∞) and perfectly inelastic (0) own-price elasticity of demand.

Concluding, assuming the Law of Demand (e.g., demand is negatively sloped) the higher the own-price elasticity of demand for BEVs (in absolute value), the more effective the subsidy is in encouraging consumers that, without the subsidization program, would have not been willing to pay for a BEV.

5. Data and Simulations' Methodology

In order to illustrate our claim, and since an econometric study was ruled out given that we could not obtain the data that would have allowed to perform it, together with the pandemic which has prevented us to conduct a reliable and unbiased survey, we have decided to use estimated own-price elasticities of demand obtained from the literature to run a few simulations.

First, it is relevant to describe some relevant data from the market provided by the Associação Automóvel de Portugal (ACAP). This institution statistics registers the number of vehicles sold every month, discriminated by model and energy (diesel, gasoline, NGV, hybrid, PHEV or BEV).

Once asked, ACAP provided the total sales for each year since 2015. In Appendix D there are Tables 15 and 16 with all models of BEVs sold between 2015 and 2018. The totals show that from 2015 to 2018 there was an exponential increase in sales from 645 to 4073. The number of different models sold also rose from 11 to 17, showing a diversification to less pollutant vehicles from different car brands.

By the end of 2019, a new record of BEVs' sales was established with 6883 units sold. Table 17, also in Appendix D, presents not only the sales for each model, but also the respective price. The price level data was collected from the website Guia do Automóvel, which provides all the technical information regarding a wide variety of car models. The link between Price/Brand Model is only possible to undertake for 2019, given that there are no data available for previous years' models.

As detailed in the literature review, subsidies cost-effectiveness depends on the buyers which are being encouraged to buy BEVs. The purpose of this section is to quantify the influence of the price elasticity of demand on non-additionality.

The simulations and the graphical analysis below require a demand and supply functions, and, therefore, different elasticities referring to different buyers. To simplify, we assume a constant elasticity demand function for battery electric vehicles where A is a constant and e_D is the own-price elasticity of demand:

$$Q = Ap^{e_D} \tag{4}$$

One possible method to find A would be to obtain total Q and an average p from Table 6. Restricting the sample to the models that cost less than 62 500€ (a requirement to apply for the subsidy), we obtain an average price of about 39 035€. However, this would not be accurate, since the quantities sold only reflect the effect of the subsidy in 2019 whilst the price levels do not. Given this limitation, A will be assumed to be 1.

Regarding the supply it is considered a linear function for simplicity:

$$Q = p \tag{5}$$

Two different simulations are run. First, we evaluate whether low income buyers, typically more price sensitive (Sheldon et al, 2019; Yang et al., 2019) should be those to be encouraged instead of those belonging to the remaining income levels plus corporations, which are expected to be less price sensitive. As stated by Zhang et al. (2016), in the case of corporate buyers the effects of both prices and incentives "are not as pronounced as with personal buyers". Then, will be assessed the consequences of an increase and decrease of the subsidy amount for the two groups mentioned above.

The literature present different values for e_D which translates the above-mentioned price sensitiveness. Xing et al. (2019) estimate a BEV e_D equal to -2.751 when considering US sales between September 2009 and August 2014. Yan (2018) uses data from 28 European countries between 2012 and 2014 and gets -1.3. Zhang et al. (2016) obtain estimates for every BEV brand sold in the city of Oslo in Norway, ranging from -0.51 (Nissan) and -81.85 (Ford) for 2011-2013 sales. Finally, Cirillo et al. (2017) estimate 4 different market elasticities relative to price in the American state of Maryland, starting at -1.32 and reaching -1.6. For the purpose of these simulations we consider e_D= -3 for the most price sensitive group and e_D = -1.1 for the higher income households and corporations. Within the literature values, these choices appear to be reasonable when trying to evaluate the differences in targeting either more or less elastic demands. The graphs which the next paragraphs refer to are available in Appendix F. The labels Q_1, Q_2, P_1, P_s and P_b represent the same values as in Figure 10. The areas in blue and red correspond to changes in consumer surplus and producer surplus respectively, while the yellow area is the deadweight loss.

The numerical values for the quantities and prices before the subsidy implementation, were reached by equating the supply and demand curve considering for each consumer group the respective own-price elasticity of demand. In order to find the equilibrium price with the subsidy, P_b was replaced in the demand function by $P_s – 3$ and then again both functions were equated. This means that in these simulations the initial subsidy amount is equal to 3 units.

On the one hand, Figure 11 illustrates the case in which the subsidy program has an income cap requirement, so that it focus on middle to low income individuals or households. Due to their higher price sensitiveness, the own price of elasticity of demand is equal to the -3 value. By focusing in such buyers' group, there is the possibility of capturing more marginal buyers, that is, those to which the policy should be targeted. The percentage of non-additionality equals 27,43% (Table 18 from Appendix E).

On the other hand, Figure 12 refers to the remainder households and corporations. From this, we can assume the lower own-price elasticity of demand, -1.1 For comparison reasons the subsidy will also be equal to 3 units instead of a smaller amount as occurs in the 2020 Portuguese subsidization program (3 000€ to households and 2 000€ to corporations). Now there will be more buyers that would have bought a BEV regardless of the existence of the subsidy. This is translated into a rise in non-additionality from previous 27,43% to 29,99% (Table 18 from Appendix E). Even though the difference between the two values is considerably small, it corroborates the literature findings that non-additionality is smaller for more price sensitive buyers.

Concerning the welfare effects and the impact in prices, when comparing Figures 12 and 13 it is possible to witness that the decrease in the equilibrium price (for buyers), before and after the subsidy implementation, is higher in the case of the group with a more inelastic price elasticity of demand (e_D = -1.1). These are the consumers who would have bought a BEV in any case given their high willingness to pay. Given this, the effects of positive externalities from CO_2 emission reductions are lowered and will not compensate as much as they are supposed to the Deadweight loss created (yellow area). Once again, by not encouraging the group with more marginal buyers, the policy is clearly not cost-effective.

The above results refer only to differences in buyers' own-price elasticities for BEVs. But what are the effects in non-additionality values when increasing the subsidy from 3 to 5 units for example or in case of budget restrictions decreasing it to 2 (as already occurs with corporations)? The results for new subsidy quantities and for N_A are presented in Tables 19 and 20 of Appendix E, respectively. Both with a 5- and 2-units subsidy, the N_A values are smaller for the low-income households, meaning that regardless of the subsidy amount these are the consumers to be encouraged.

a. Policy Recommendations

Given the above findings, the subsidization program should focus mainly in more price sensitive buyers, such as medium to low income consumers through a mandatory presentation of the previous year IRS (i.e "Imposto sobre o Rendimento de Pessoas Singulares") declaration. This would decrease the portion of BEVs which would have been bought regardless the existence of the incentive. In other words, with the same amount of resources, the subsidy would encourage a greater share of buyers who would not afford to buy a battery electric vehicle.

Concerning corporations, it is acceptable that the Portuguese government, due to budget restrictions, decides to set a lower value, reducing the number of applications by companies. Moreover, and as detailed in section 3, firms already benefit from large tax incentives, which not only decrease the final purchase price, but also result in considerable savings throughout the BEV life cycle.

Finally, the per unit subsidy amount should increase to values closer to the other European countries (Figure 13, Appendix F), given that the purchasing price for a BEV is still far from what people are willing to pay (Liu, 2014). Regardless of the subsidy amount, as observed in the previous quantitative analysis, the most cost-effective option would be to subsidize low income buyers given that their non-additionality percentage is lower than the one corresponding to the least price sensitive group.

6. Conclusion and Discussion

Environmental concerns are in the 21st century in the core of major debates not only in Europe but all around the world. The pursuit of sustainable and environmentally friendly options is no longer a matter for a residual portion of consumers, it is for sure a global fight where the States and the business sector can act as changemakers.

With the aim of achieving carbon neutrality, several nations and regions are trying to encourage their citizens to buy Electric Vehicles through different tax incentives and subsidies. Portugal is not an exception and there is currently a subsidization program focused, not only in Battery Electric Vehicles, but also in other fully electric vehicles, such as bikes or motorcycles.

This program, specifically in what concerns BEVs, was the theme for this thesis. Data simulations were implemented to evaluate whether the scheme, as it is set, is effective in promoting additionality and preventing non-additionality. Based on Xing et al. (2019) it was shown that own-price elasticities of demand are a key factor in determining the percentage of BEVs which would have been bought even without the subsidy, that is, non-additionality.

Even though the non-representativeness and bias of the survey must be taken into account, it was possible to point out that within the 215 individuals (disregarding students and who preferred not to specify their income range) which WTP is below 25 000€, around 76% (165/215 * 100 in Table 14) earn less than 1 500€ per month as net income.

Concerning simulations' results, when introducing an income requirement to the program, the non-additionality percentage equals is about 27,43% given that it is subsidizing low income earners, more price sensitive (e_D = -3). However, the 27,43% rises to 29,99% when focusing in corporations and higher income households. This means that with the same public expenditures, the subsidy design becomes more cost-effective when encouraging buyers with lower income, given that in this group there are relatively fewer BEV's potential buyers obtaining a subsidy which they would not need to buy the vehicles. In other words, the subsidy incentivizes the marginal buyers that otherwise could not afford to buy an electric vehicle, promoting additionality. Therefore, by using the public resources to subsidize those buyers, a net increase in the amount of electric vehicles would accrue, with a positive impact on emissions reduction.

Therefore, the subsidies should discriminate across buyers by targeting them according to their income level. This is in contrast to the current policy followed by the Portuguese Government.

The graphical analysis represents the result that by subsidizing high income households or corporations with a more inelastic own price elasticity of demand for BEVs, the government “forces” the decrease of the equilibrium price for a group of consumers whose willingness to pay was already above the initial price. Moreover, this decrease in price is even higher than the one registered once subsidizing low income households, which are the ones to have a greater number of marginal buyers in need for the grant. This again, sends the message that such policy is not cost effective, and the predicted environmental positive externalities will not be as strong as they are supposed to, so that they can somehow compensate for the deadweight loss presented int the yellow area.

When answering to the proposed research question we may state, by the abovementioned findings, that without any specific requirements besides the 62 500€ price limit, the Portuguese subsidization program is not effectively encouraging consumers that are not able to buy a BEV without the monetary incentive, the “right consumers”.

This work project is not exempt from either data or methodology flaws. However, given the data available, it is an important starting point for further research in the topic. Ideally, a thorough analysis would require a complete database of Portuguese Battery Electric Vehicles sales in recent years, also providing information about buyers’ characteristics, such as income, gender, age, home location, among others. Without this information and estimates, public money is misallocated.

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Appendix A

Table 4: Survey Details

Question number	Questions	Options
1	What is your gender?	**a.** Male **b.** Female **c.** Other
2	How old are you?	**a.** 20 - 25 **b.** 25 - 35 **c.** 35 - 45 **d.** 45 - 55 **e.** 55 - 65 **f.** +65
3	What is your net monthly income (in €)?	**a.** I am a student, with no earnings. **b.** 0 – 500 **c.** 500 – 1000 **d.** 1000 – 1500 **e.** 1500 – 2000 **f.** 2000 – 2500 **g.** + 2500
4	Have you ever thought about purchasing a Battery Electric Vehicle?	**a.** Yes. **b.** No. **c.** I alread owe a BEV.
5	What were/would for you the reasons to purchase a BEV?	**a.** It is a sustainable and environmentally friendly option. **b.** Because of the existence of governmental subsidies. **c.** For the long-run savings. **d.** All the previous options.
6	On average, how many kms do you drive per day?	**a.** 0 – 20 **b.** 20 – 40 **c.** 40 – 60 **d.** 60 – 80 **e.** 80 – 100 **f.** 100 – 150 **g.** 150 – 200 **f.** + 200

7	What would you be willing to pay for a BEV (in €)?	**a.** 15 000 – 20 000 **b.** 20 000 – 25 000 **c.** 25 000 – 30 000 **d.** 30 000 – 35 000 **e.** 35 000 – 40 000 **f.** 40 000 – 45 000 **g.** 45 000 – 50 000 **h.** 50 000 – 55 000 **i.** 55 000 – 60 000 **j.** + 60 000
8	Imagine that you have at your disposable two similar cars, with the exception that one would be an ICE model and the other a BEV. How much more would you be willing to pay, in order to buy the full electric vehicle (in €)?	**a.** 0 **b.** 100 – 500 **c.** 500 – 1000 **d.** 1000 – 2000 **e.** 2000 – 3000 **f.** + 3000
9	Have you ever heard about the 3000€ incentive to reduce the purchasing price of a BEV?	**a.** Yes. **b.** No.

Source: Own Source

Appendix B

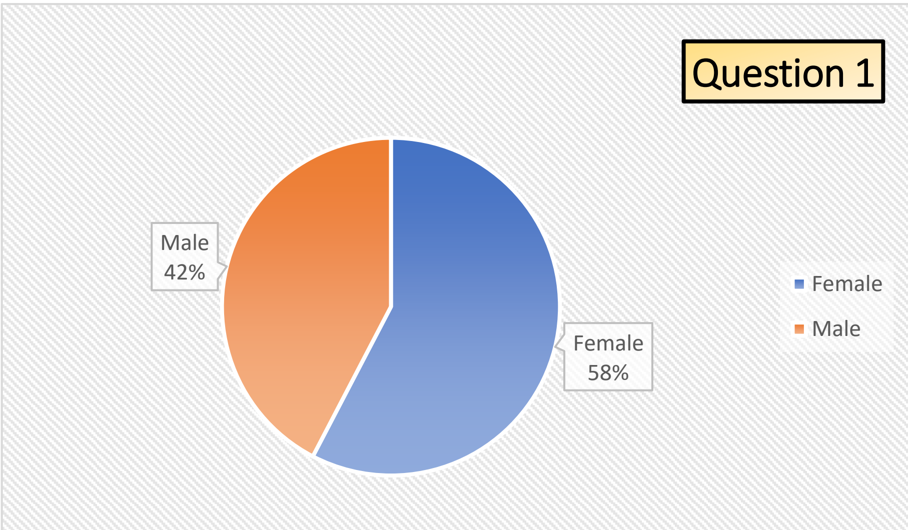

Figure 1: Question 1 results in % terms

Source: Survey

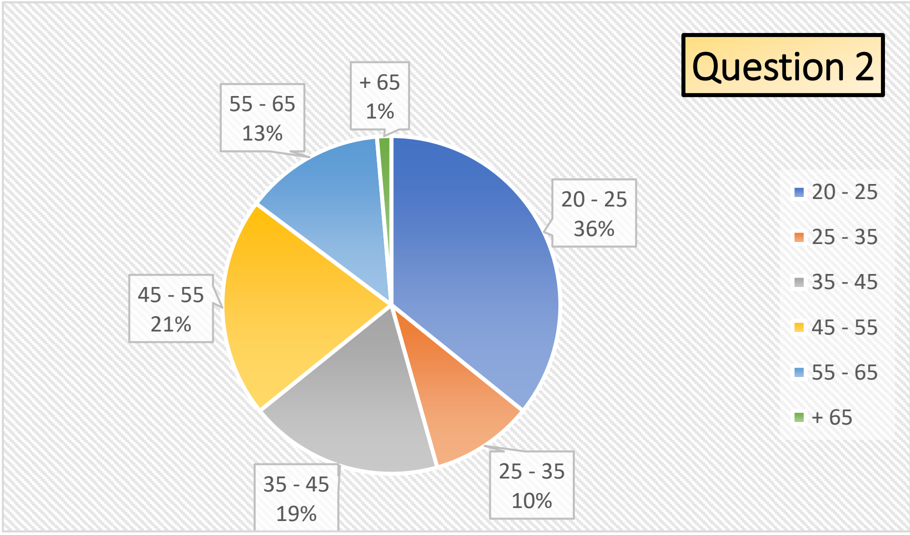

Figure 2: Question 2 results in % terms

Source: Survey

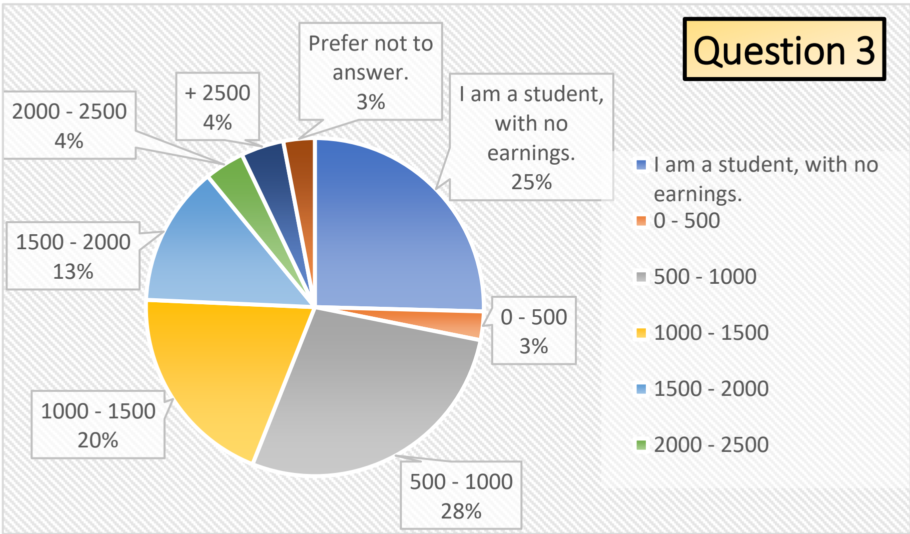

Figure 3: Question 3 results in % terms

Source: Survey

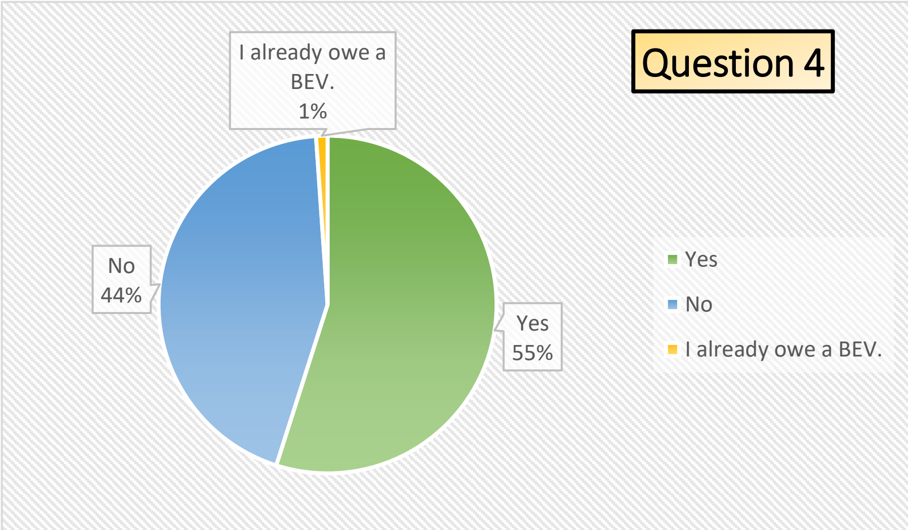

Figure 4: Question 4 results in % terms

Source: Survey

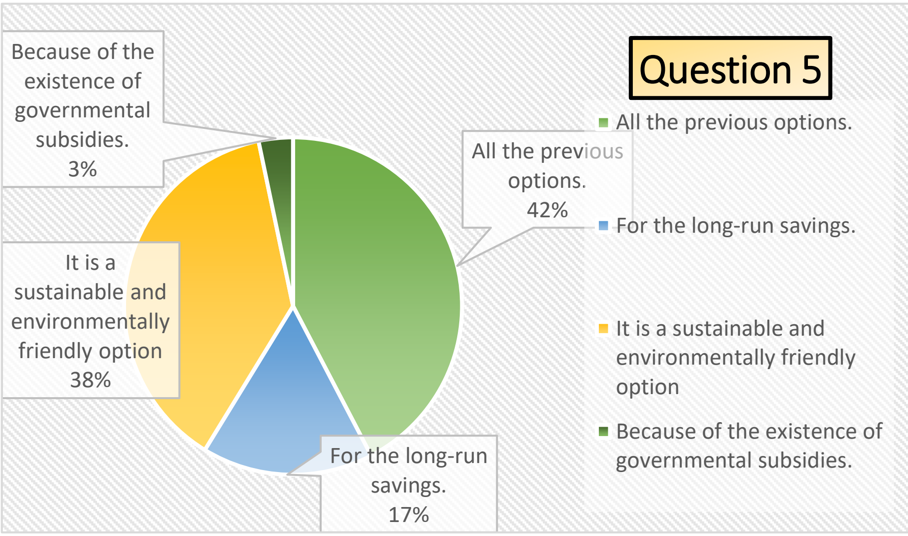

Figure 5: Question 5 results in % terms

Source: Survey

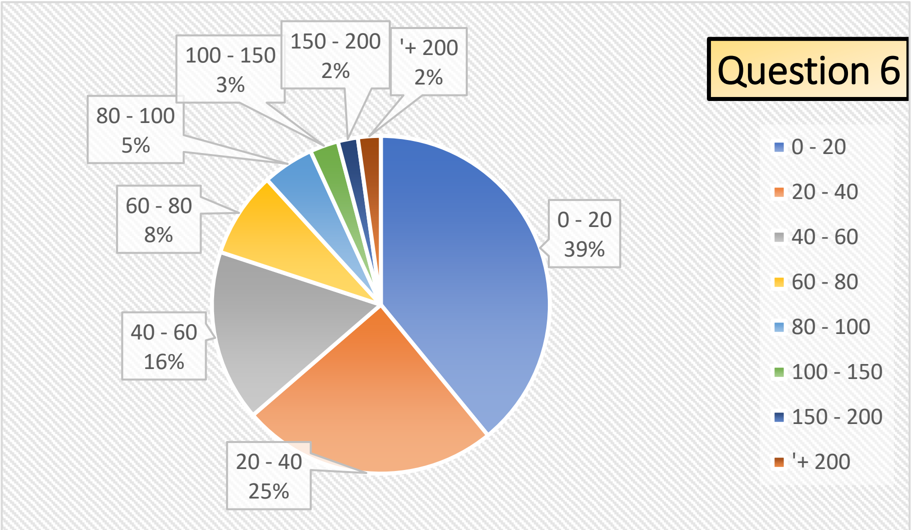

Figure 6: Question 6 results in % terms

Source: Survey

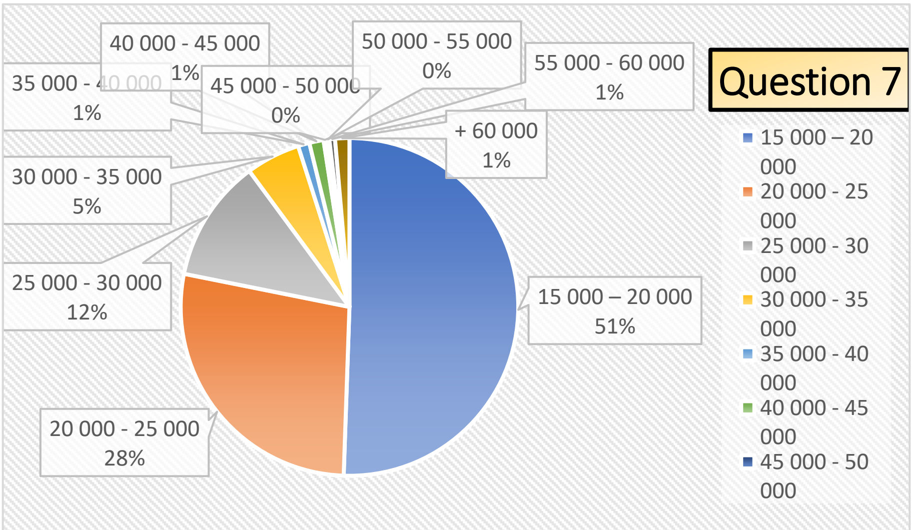

Figure 7: Question 7 results in % terms

Source: Survey

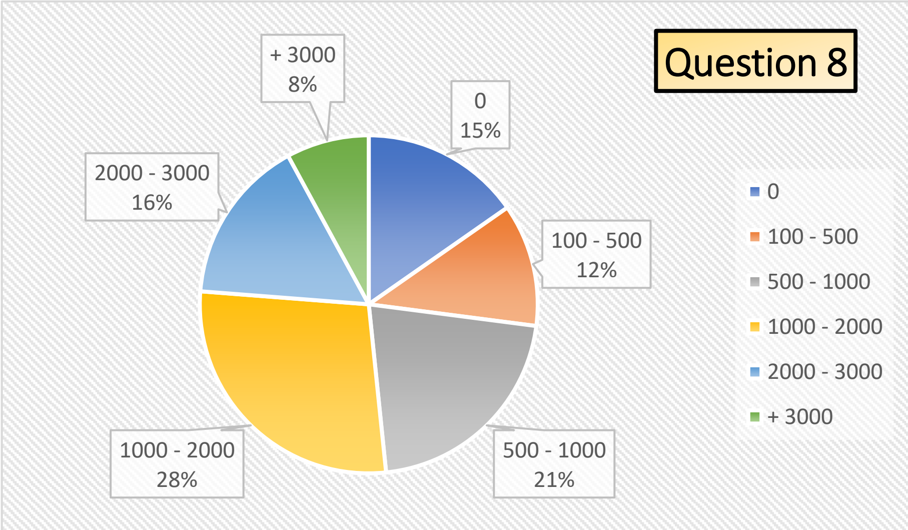

Figure 8: Question 8 results in % terms

Source: Survey

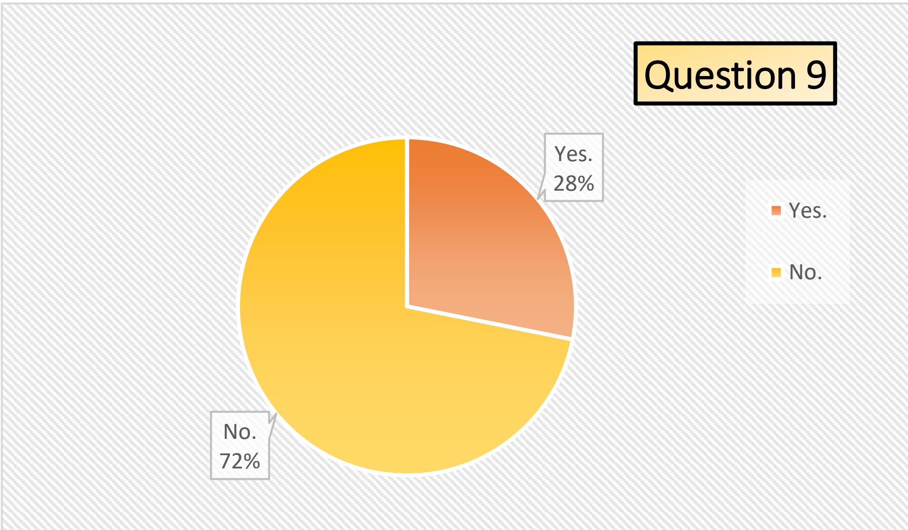

Figure 9: Question 9 results in % terms

Source: Survey

Appendix C

Table 5: Question 1 results in absolute terms

Question 1	
Options	**# of answers**
Female	211
Male	155

Source: Survey

Table 6: Question 2 results in absolute terms

Question 2	
Options	**# of answers**
20 - 25	131
25 - 35	36
35 - 45	68
45 - 55	77
55 - 65	49
+ 65	5

Source: Survey

Table 7: Question 3 results in absolute terms

Question 3	
Options	**# of answers**
I am a student, with no earnings.	93
0 - 500	10
500 - 1000	102
1000 - 1500	72
1500 - 2000	49
2000 - 2500	14
+ 2500	15
Prefer not to answer.	11

Source: Survey

Table 8: Question 4 results in absolute terms

Question 4	
Options	**# of answers**
Yes	201
No	161
I already owe a BEV.	4

Source: Survey

Table 9: Question 5 results in absolute terms

Question 5	
Options	**# of answers**
Because of the existence of governmental subsidies.	12
For the long-run savings.	60
It is a sustainable and environmentally friendly option	139
All the previous options.	155

Source: Survey

Table 10: Question 6 results in absolute terms

Question 6	
Options	**# of answers**
0 - 20	143
20 - 40	90
40 - 60	60
60 - 80	30
80 - 100	18
100 - 150	10
150 - 200	7
+ 200	8

Source: Survey

Table 11: Question 7 results in absolute terms

Question 7	
Options	**# of answers**
15 000 – 20 000	185
20 000 - 25 000	101
25 000 - 30 000	43
30 000 - 35 000	19
35 000 - 40 000	4
40 000 - 45 000	5
45 000 - 50 000	1
50 000 - 55 000	1
55 000 - 60 000	2
+ 60 000	5

Source: Survey

Table 12: Question 8 results in absolute terms

Question 8	
Options	**# of answers**
0	56
100 - 500	43
500 - 1000	78
1000 - 2000	102
2000 - 3000	58
+ 3000	29

Source: Survey

Table 13: Question 9 results in absolute terms

Question 9	
Options	**# of answers**
Yes.	103
No.	263

Source: Survey

Appendix D

Table 15: Number of BEVs' models sold in 2015 and 2016

Brand	Model	2016	2015
NISSAN	LEAF	328	209
BMW	SÉRIE i3	177	128
RENAULT	ZOE	170	153
KIA	SOUL	31	3
VOLKSWAGEN	GOLF	18	15
MERCEDES-BENZ	CLASSE B	14	17
VOLKSWAGEN	UP!	8	22
PEUGEOT	ION	6	58
CITROËN	C-ZERO	2	27
SMART	FORTWO	1	7
MITSUBISHI	I-MIEV	1	6
Total		**756**	**645**

Source: ACAP

Table 16: Number of BEVs' models sold in 2017 and 2018

Brand	Model	2018	2017
NISSAN	LEAF	1593	318
RENAULT	ZOE	1305	751
BMW	SÉRIE i3	363	255
SMART	FORTWO	220	90
CITROËN	C-ZERO	159	5
SMART	FORFOUR	126	47
KIA	SOUL	79	60
HYUNDAI	IONIQ	74	24
VOLKSWAGEN	GOLF	55	43
JAGUAR	I-PACE	23	0
NISSAN	e-NV200	18	0
CITROËN	BERLINGO	16	6
HYUNDAI	KAUAI	15	0
VOLKSWAGEN	UP!	14	20
PEUGEOT	PARTNER TEPEE	11	5
PEUGEOT	ION	2	8
MERCEDES-BENZ	CLASSE B	0	8
Total		**4 073**	**1640**

Source: ACAP

Table 17: Number of BEVs sold per model and respective unit price in 2019

Brand	Model	# of vehicles sold	Price
NISSAN	LEAF	1662	34 505,20 €
TESLA	MODEL 3	1543	50 905,20 €
RENAULT	ZOE	968	32 245,20 €
BMW I	SÉRIE i3	586	42 100,00 €
JAGUAR	I-PACE	540	81 114,00 €
HYUNDAI	KAUAI	425	39 105,20 €
SMART	FORTWO	249	22 845,00 €
TESLA	MODEL S	243	86 998,90 €
TESLA	MODEL X	193	95 995,20 €
SMART	FORFOUR	158	23 745,00 €
HYUNDAI	IONIQ	101	40 580,20 €
VOLKSWAGEN	GOLF	79	42 816,20 €
AUDI	E-TRON	53	72 740,80 €
NISSAN	e-NV200	34	30 000,00 €
KIA	SOUL	30	48 073,50 €
MERCEDES-BENZ	EQC	8	79 150,00 €
DS	DS 3 CROSSBACK	5	41 300,00 €
KIA	NIRO	2	49 573,50 €
VOLKSWAGEN	UP	2	23 380,10 €
CITROEN	C-ZERO	1	30 646,90 €
PEUGEOT	PARTNER	1	33 809,00 €
Total		**6883**	

Source: ACAP and Guia do Automóvel, 2020

Appendix E

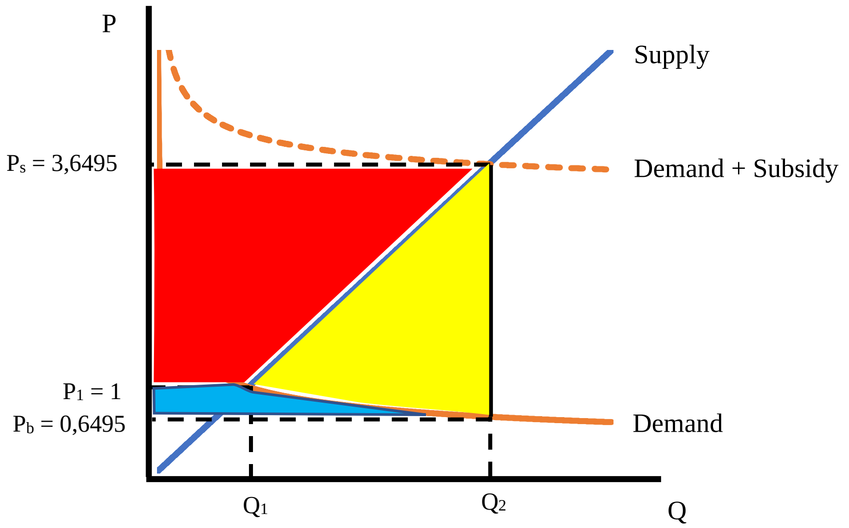

Figure 11: Welfare effects of the 3-unit subsidy in the low-income buyers’ group

Source: Own Source

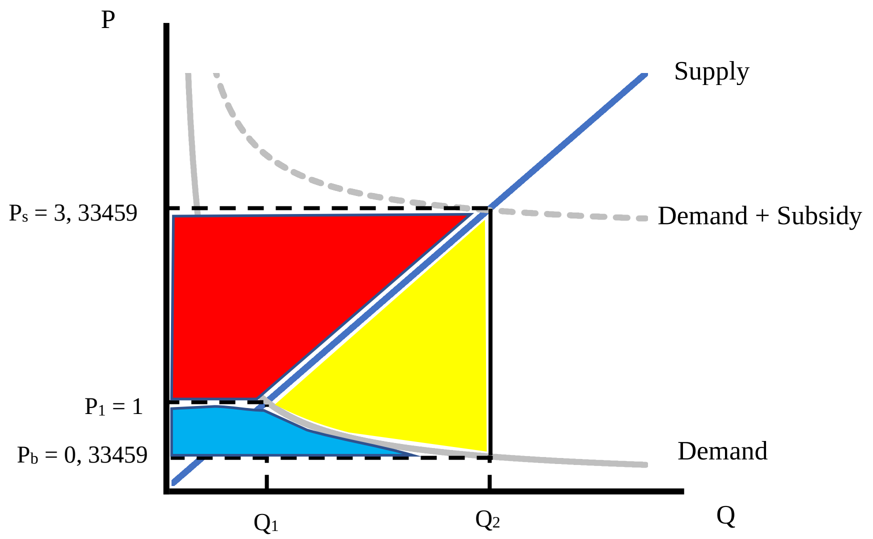

Figure 12: Welfare effects of the 3-unit subsidy in the high-income households and corporations’ group

Source: Own Source

Table 18: Quantities and N_A with 3-unit subsidy for the 2 buyers' groups

Parameters	Low income households	High income household and Corporations
e_D	-3	-1,1
Initial quantity (Q_1)	1	1
Subsidy quantity (Q_2)	3,64595	3,33459
N_A	27,43%	29,99%

Source: Own source

Table 19: Quantities and N_A with 5-unit subsidy for the 2 buyers' groups

Parameters	Low income households	High income household and Corporations
e_D	-3	-1,1
Initial quantity (Q_1)	1	1
Subsidy quantity (Q_2)	5,5643	5,22253
N_A	17.97%	19,15%

Source: Own source

Table 20: Quantities and N_A with 2-unit subsidy for the 2 buyers' groups

Parameters	Low income households	High income household and Corporations
e_D	-3	-1,1
Initial quantity (Q_1)	1	1
Subsidy quantity(Q_2)	2,7167	2,44382
N_A	36,81%	40,92%

Source: Own source

Appendix F

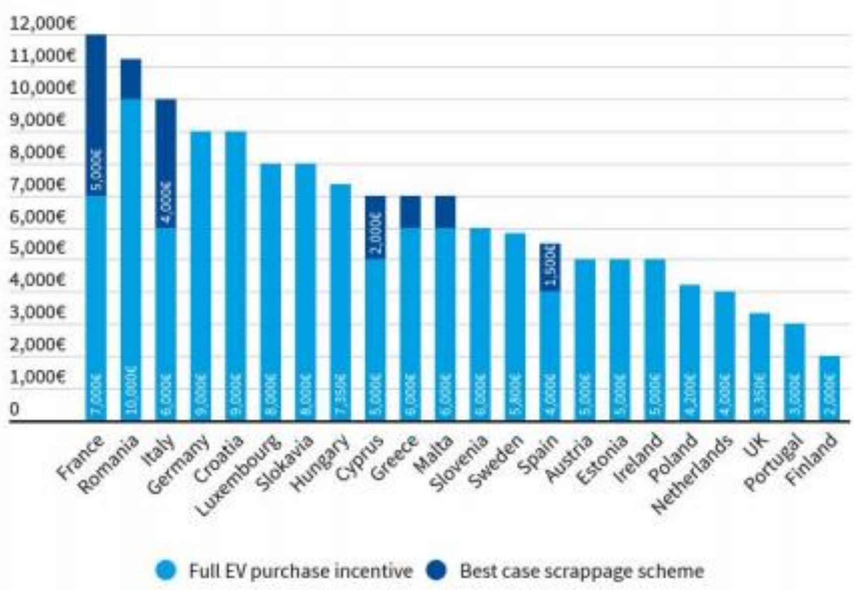

Figure 13: BEVs purchase subsidies and scrappage schemes in Europe (as of summer 2020)

Source: Transport & Environment (2020). Mission (almost) accomplished, page 18